L7: Entry 7 of 7 File: USPT Feb 20, 2001

DOCUMENT-IDENTIFIER: US 6192314 B1
TITLE: Method and system for route calculation in a navigation application

Brief Summary Text (3):
Computer-based navigation systems are able to provide end-users, such as vehicle drivers and as well as others, with various navigating functions and features. For example, some navigation systems are able to determine an optimum route to travel by roads between locations in a geographic region. Using input from the end-user, and optionally from equipment that can determine the end-user's physical location (such as a GPS system), a navigation system can examine various routes between two locations to determine an optimum route to travel from a starting location to a destination location in the geographic region. The navigation system may then provide the end-user with information about the optimum route in the form of instructions that identify the maneuvers required to be taken by the end-user to travel from the starting location to the destination location. The navigation system may be located in an automobile and the instructions may take the form of audio instructions that are provided as the end-user is driving the route. Some navigation systems are able to show detailed maps on computer displays that outline routes to destinations, the types of maneuvers to be taken at various locations along the routes, locations of certain types of features, and so on.

Detailed Description Text (19):
Referring to FIG. 5, the configuration object 64 is a data structure that holds parameters 64 (1) . . . 64(n), which are used to control the route calculation object 50. Some or all of these parameters may be configurable by the end-user. Some of these parameters may include items, such as weighting factors, that may be used in route calculation. For example, these parameters may include "avoid highways," "avoid U-turns," "determine shortest route," "determine quickest route," etc. These parameters may also include the maximum layer of map data (as represented in FIG. 3) at which route searching is to be performed and whether the route searching should use logical or physical suppression to enforce the maximum layer. Some configurable parameters in the configuration object 64 may be selected by the navigation system manufacturer or by a service technician and thus may not be configurable by the end-user. The data included in the configuration object 64 is stored in a re-writable and non-volatile memory of the navigation system, such as the non-volatile memory 16 (in FIG. 1).

Detailed Description Text (21):
Referring to FIG. 6, the vehicle object 68 is a data structure that includes data 68(1) . . . 68(n) that provide the characteristics of the vehicle for which the route will be calculated by the route calculation tool 40. Under some circumstances, characteristics of the vehicle may affect generation of the route. For example, the vehicle object 68 may include data that indicates that the vehicle is a truck having a given weight and number of axles. In such a case, the route searching tool 40 ensures that the calculated route include only roadways with weight limits that allow such a vehicle. In another example, the vehicle object 68 may include information indicating that the vehicle is a passenger vehicle having more than one person on board. The route searching tool 40 can then include lanes restricted to multiple passenger vehicles. The data included in the vehicle object 68 is stored in a re-writable and non-volatile memory of the navigation system, such as the non-volatile memory 16 (in FIG. 1). Some or all of the data in the vehicle object 68 may be configurable by the end-user. Alternatively, some or all may be determined by the navigation system manufacturer or a technician.

Detailed Description Text (71):
Referring again to FIG. 13, to perform route searching, the route calculation object 50 creates and uses at least two search tree objects 140. The two search trees objects include an outbound search tree object 140(OUT) and an inbound search tree object 140(IN).

Detailed Description Text (72):
The search tree objects 140 are parts of the route calculation object 50. The search tree objects 140 are used internally by the route calculation object 50 and thus are transparent to the remainder of the route calculation tool 40. Each search tree object 140 defines and holds information used for route searching. Specifically, each search tree object 140 holds a search tree 141 (shown in FIGS. 15 and 16) formed of gates 124 associated with a respective one of the waypoints. When calculating a route between an origin waypoint and a destination waypoint without any intermediate stops, the outbound search tree 141(OUT) is associated with the origin waypoint and the inbound search tree 141(IN) is associated with the destination waypoint. However, if there are intermediate waypoint stops, multiple inbound and outbound search tree pairs are created and used successively by the route calculation object 50, one pair for each leg of the route. For example, if there is one intermediate waypoint, a first outbound search tree 141(OUT) is used for the origin waypoint and a first inbound search tree 141(IN) is used for the intermediate stop waypoint. After a route between the origin and the intermediate waypoint stop is calculated, the route calculation object 50 creates two new search trees. A second outbound search tree 141(OUT) is used for the intermediate waypoint and a second inbound search tree 141 (IN) is used for the destination waypoint. Additional search tree pairs may be formed and used if there is more than one intermediate stop. (As explained further below, for certain kinds of searches each search tree object may be associated with more than one waypoint.)

Detailed Description Text (98):
Referring again to FIG. 13, when performing route searching, the route calculation object 50 creates and uses two priority queue objects 150. In a preferred embodiment, each search tree object 140 is associated with a priority queue object 150. The priority queue objects include an outbound priority queue object 150(OUT) associated with the outbound search tree object 140 (OUT) and an inbound priority queue object 150(IN) associated with the inbound search tree object 140(IN).

Detailed Description Text (103):
Referring to FIG. 14, in the inbound priority queue object 150(IN), an order of priority is assigned to these raw successor gates 124 using a search algorithm 170. Any known method or algorithm 170 may be used for this purpose. For example, the method used may be the A* algorithm or the Dykstra algorithm. To use the A* algorithm, the route calculation object 50 calls the algorithm 170 with a pointer to the data in each of the gates which are referenced in the priority queue 150. The route calculation engine 160 may also pass the focus or a pointer to the focus to the algorithm 170. The algorithm evaluates each of the gates referenced in the priority queue relative to the focus 143(IN). An advantage provided by this approach is that the method used for route searching is configurable. For example, the A* algorithm may be modified to the Dykstra algorithm by setting the heuristic variable to zero. A default algorithm may be provided with the route calculation tool 40. The navigation application 47 can provide an algorithm in substitution of the default algorithm. Alternatively, other route searching techniques or algorithms may be substituted. For example, when the A* algorithm is used, the highest priority gate is the one with the lowest overall combined actual and heuristic costs. Using the algorithm 170, a weighting is assigned to each of the unexpanded gates referenced in the priority queue 150(IN).

Detailed Description Text (117):
After a potential solution route is found, route searching may be continued to find additional solution routes between the two waypoints until a termination criterion is met. The termination criterion can be some combination of number of potential solutions, quality (cost) of the solutions, time elapsed in the search, etc. A present embodiment finds one solution, then expands all the gates in the priority queue, without adding any new gates to the priority queue. This may produce additional solution candidates. The termination criterion may be stored in the configuration object 64 of FIG. 4.

Detailed Description Text (125):
Although the embodiments of the route calculation tool 40, described above, provide for significant advantages for route searching when used as part of a navigation application program 18, many of the significant advantages and benefits derive from the features that the tool enables or makes more efficient. Some of these features are described below.

Detailed Description Text (141):

Using physical rank suppression, the road segment records are retrieved only from the layer of the map database 30 that contains segment records at or above the specified rank. By eliminating segment records of lower ranks from consideration in route searching, fewer road segment records need be evaluated or explored to determine the solution route (i.e., fewer gates will be generated in the search tree for expansion). The layer to be used may be determined for each gate independently of the layers used for the other gates.

Detailed Description Text (157):
Using this embodiment, a road of low or medium rank can be evaluated for a solution route if its geographical distance to the tree focus point is shorter than the tree focus gap plus the focus ring width. As can be appreciated from examining FIG. 21, by not suppressing lower ranked segments within the focus ring, there exists the possibility that promising lower ranked roads may be incorporated into a solution route. In order to be used in a solution route, a route that incorporates such lower ranked roads would still have to provide a lower overall cost compared to any of the other potential routes being explored. However, using the disclosed embodiment, lower ranked roads may be considered even if they may be located relatively far from a waypoint. This embodiment still suppresses consideration of lower ranked roads that are unlikely to form low cost solution routes, such as the roads outside the outer boundary of the focus ring. Thus, by selectively suppressing roads in this manner, a quality route can be calculated relatively quickly.

Detailed Description Text (159):
As the search tree is being grown, a determination is made of the road density at some interval of tree growth, as described above. A road density determination is made by comparing the tree height to the distance from the waypoint of the most recently added gate. If this comparison indicates that the road network is relatively sparse, the widths of the focus ring and sub-rings are increased. This may be accomplished by applying a proportionate scaling factor to the default ring sizes. Like the sizes for the zones, a proportionate scaling factor to be applied may be based upon empirical or experimental analysis. For example, experiments may show that a focus ring width of 10 km provides the best routes quickly for rural areas and that a focus ring width of 5 km provides the best routes quickly for urban areas. If a road density is measured that is between these two limits, an appropriate scaling factor is applied to determine a size between 5 and 10 km for the focus ring width proportionate to the measured density between these limits. It is noted that different default sizes may be appropriate for different countries or regions within a country. These default ring sizes may be determined experimentally.

Detailed Description Text (160):
There are several distinct advantages associated with the disclosed rank suppression embodiment. A route calculation program utilizing this rank suppression feature has the potential to outperform other route calculation programs in quickly finding routes of high quality, especially for hard problem instances. First, with this embodiment, a main portion of the search is conducted in a relatively small zone region of the waypoint of the search tree towards a focus point. This significantly reduces amount of memory used as well as route calculation time. Second, the present embodiment allows searching roads of medium or low rank as they appear to be promising in a poorly connected road network. Thus, the present embodiment is more likely to finds routes of high quality than prior route calculation programs. In a poorly connected road network, any route of reasonable quality is required to use some lower ranked roads. For long range route calculations, prior algorithms may fail to find quality routes because they search only high ranked roads in the middle of the journey. With the present embodiment, the search for a route can readily use lower layers as well as higher layers of data, even along a middle portion of a calculated route.

Detailed Description Text (165):
Once the navigation position object 56 corresponding to the current vehicle position is obtained, it is provided to the navigation application 47. The navigation application 47 creates a waypoint object 100 and provides it to the route calculation tool 40 which is operated in a rerouting mode. According to one embodiment, operation of the route calculation tool 40 in the rerouting mode is similar to the operation for normal route searching. An inbound search tree object 140(IN) and an outbound search tree object 140(OUT) are formed by the route calculation object 50. The route calculation object 50 uses the waypoint object 100 that represents the current vehicle position to obtain portal information from which seed gates 108 can be determined for a new outbound search tree 141(OUT). These new seed gates and immediate successor gates of these seed gates are determined and added to a new outbound search

tree 141(OUT) in a new outbound search tree object 140(OUT). As mentioned above, the inbound search tree 141(IN) is the augmented inbound search tree that contains the previously calculated inbound search tree for the original solution route as well as any gates that were part of the original solution route but which were in the original outbound search tree 141 (OUT). As in a normal search, the gates in these new inbound and outbound search trees are compared to determine whether the same gate exists in both the new inbound and outbound search trees. If it does, a solution route exists and the list of segments that form the solution route is placed in an output route object 60.

Detailed Description Text (166):
If a solution route was not found in the previous step, the inbound tree 141(IN) is grown. The current vehicle position may be used as the focus 143(IN) of the inbound search tree 141(IN). Pointers to all the unexpanded gates in the new inbound search tree 141(IN) are stored in a new inbound priority queue object 150(IN). As in the first described embodiment, any suitable route searching algorithm may be used to establish a priority among the unexpanded gates in the inbound search tree. When used for rerouting, the route searching algorithm evaluates each of the positions of the unexpanded gates relative to the focus 143(IN) which in the rerouting mode corresponds to the current vehicle position. (An alternate priority algorithm may be used during rerouting to give higher than usual priority to gates that are close to the new origin. Since the new origin is usually near the old route, this tends to cause the new route to converge to the old route more quickly.)

Detailed Description Text (169):
In an alternative embodiment, the original solution route is placed in an input route object 72. When a previous route is used in this manner, it may be referred to as a nexus. A nexus is a list of segment records that together form all or part of a route. A nexus is used to constrain the route searching performed by the route calculation object 50. When a node of a nexus is encountered while route searching is being conducted, the nexus is followed from the encountered node to the end of the nexus, from which further route searching may be performed. Thus, when reroute searching is performed and a point on the original route (represented by the nexus) is encountered, the rerouting is constrained to follow the remainder of the original solution route to the destination waypoint. This provides an advantage since a determination had been made during calculation of the original route that such route represented the best route according to the chosen parameters.

Detailed Description Text (170):
The rerouting feature provided by a present embodiment of the route calculation tool 40 provides a significant advantage over prior route searching programs. In prior programs, searches for rerouting were performed from the vehicle position to the destination. However, since the vehicle's position is continually changing as the vehicle moves, rerouting searches required the route calculation application to predict an origin of the search ahead of the vehicle. The present embodiment avoids the need to predict an origin ahead of the vehicle because the rerouting search is performed from the existing inbound tree towards the changing vehicle position or focus. This calculation can be performed relatively quickly because the vehicle position waypoint (used as the focus of the inbound search tree) represents a relatively small item of information that changes. The larger amount of information resides in the inbound search tree, which does not need to be changed.

Detailed Description Text (175):
Another advantageous feature that may be provided by an alternative embodiment of the route calculation tool 40 is the determination of routes passing through multiple intermediate waypoints. To provide for one or more intermediate waypoints, the first intermediate waypoint is treated as a destination waypoint, and a route is determined between the origin waypoint and the first intermediate waypoint according to the method described above. Once a solution route to the first intermediate waypoint is found, the first intermediate waypoint is treated as the origin waypoint and the second intermediate waypoint is treated as a destination waypoint. The route searching method described above is again repeated, and so on, until a solution route is determined between the last intermediate waypoint and the ultimate destination waypoint. At that stage, the route calculation engine 160 concatenates the routes determined between the various waypoints to provide a single route from the origin waypoint to the destination waypoint passing through all of the intermediate waypoints. Customized information about the road network, such as nexuses and masked segments are retained for each leg of the route calculation.

Detailed Description Text (178):
For determining alternate routes, a first solution route is found according to any of the methods described above. Then, the costs of traversing the road segments that comprise the first route are increased. Segments having these artificially raised costs are called "masked segments." The previously described route searching method is then repeated to calculate a second or alternate route. When gates of the first route are encountered in the search tree, they will have higher costs than when previously encountered. These higher costs will be reflected in the priority assigned to each of these gates in the priority queue. These higher costs reduce the likelihood that any of the gates from the original solution route will be selected thus helping to ensure that an alternate route will be found with only minimal overlap between the original and alternate routes. Once a second route is determined, its segments may be masked and the procedure may be repeated to determine yet another additional alternate routes, and so on.

Detailed Description Text (183):
An embodiment of the route calculation tool 40 also provides a mechanism for the navigation application 47 to incorporate real time traffic information in the route calculation determination. The route calculation tool 40 may provide for accepting input about the cost of traversing a segment taking into account traffic conditions. For example, the cost of a segment may be increased due to rush hour traffic or an inhibiting traffic incident. This information may be provided to the navigation system by wireless transmission from a traffic monitoring service. The route calculation object 50 can check and account for such traffic information as each gate is expanded in a search tree.

Detailed Description Text (185):
As mentioned above, a route object can be used as an input ("72" in FIG. 4) to the route calculation object 50. When used in this manner, the previous route is incorporated as part of a new route being calculated. When a previous route is used in this manner, it is referred to as a nexus, as mentioned above. A nexus is used to constrain the route searching performed by the route calculation object. When any location along a route represented by a nexus is encountered while route searching is being conducted, the nexus is followed from the point of encounter to the destination end of the nexus. Further route searching may be performed from the destination end of the nexus. A route object used as a nexus includes an entire route and may have a format identical to the route object. The route object used as a nexus may be a route object previously calculated by the route calculation tool or may be provided by another source.

Detailed Description Text (194):
Multiple origin waypoints and/or multiple destination waypoints can also be used to find the lowest cost route to any of a variety of destinations. For example, if an end-user wants to visit any one of four restaurants, each of these restaurants can be represented by a destination waypoint. Four destination waypoint objects are formed and seed gates for each are added to an inbound search tree. The route calculation tool is operated and a solution route of minimum cost is found to one of the restaurants.

Detailed Description Text (200):
Present embodiments provide a concise data model used for searching optimum routes in a complex road network. This data model includes search trees and data structures such as gates, waypoints, and portals. These structures enable the navigation application to provide detailed instructions to an end-user in a road network with various constraints such as irregular start and end locations. Conventional approaches (e.g., graph theory applications) would require data models of much larger size in these types of road networks.

Detailed Description Text (201):
Present embodiments also provide a new road search suppression heuristic developed for speeding up the search, especially for long range route searches. Low rank roads are quickly eliminated from consideration except in a generic ring shaped region relative to a specified focus point (e.g., the origin, the destination, or an intermediate waypoint). The size of the main search region is relatively small, depending on the road structure and the search position. Moreover, this generic search region is configurable with a set of tunable parameters for further performance improvement. The search heuristic significantly reduces route calculation time and memory usage while it finds routes of high quality.

CLAIMS:

16. A route calculation tool program for use in a navigation system and adapted to calculate a route between a first location and a second location, said route calculation tool program comprising:

object logic operatively executed by a processor of said navigation system, the object logic comprising a plurality of independent program objects, wherein each program object receives input data and provides output data according to a property of the program object, wherein said route calculation tool program comprises:

at least one of the program objects comprising a route calculation program object operatively adapted to receive a first waypoint program object representing said first location and a second waypoint program object representing said second location;

wherein said route calculation program object further comprises:

an outbound search tree program object including at least one seed gate and successor gates thereof, wherein said at least one seed gate represents a position along a road segment from which the first location can be exited, said position derived from said first waypoint program object;

an inbound search tree program object including said at least one seed gate and successor gates thereof, wherein said at least one seed gate represents a position along a road segment into which the second location can be entered, said position derived from said second waypoint program object;

an outbound priority queue program object including prioritized references to unexpanded gates in said outbound search tree program object; and

an inbound priority queue object including prioritized references to unexpanded gates in said inbound search tree program object; and

wherein at least one of said search tree program object is adapted to grow by expanding the gates therein to find a solution route when said search tree program objects include at least one common gate.

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Search Results -

Terms	Documents
increas$3 and L8	1

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Search: L19

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DATE: Sunday, July 24, 2005 Printable Copy Create Case

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L18	l8 and list	1	L18
L17	transit and l8	0	L17
L16	cell and l8	0	L16
L15	l8 and L14	1	L15
L14	circular or square	2219600	L14
L13	map and l8	2	L13
L12	l10 and L11	1	L12
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L9	cost	2521308	L9
L8	6192314.pn.	2	L8
L7	l5 and L6	7	L7
L6	(cost or fee or toll) adj (region or segment)	384	L6
L5	l3 and L4	65	L5
L4	(best or optimum) adj (route or road)	3923	L4
L3	l1 and L2	224	L3

L2	(low or minimum) adj cost	622693	L2
L1	route adj search$3	3156	L1

END OF SEARCH HISTORY

Refine Search

Search Results -

Terms	Documents
L5 and L6	7

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Search: L7

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Search History

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L6	(cost or fee or toll) adj (region or segment)	384	L6
L5	l3 and L4	65	L5
L4	(best or optimum) adj (route or road)	3923	L4
L3	l1 and L2	224	L3
L2	(low or minimum) adj cost	622693	L2
L1	route adj search$3	3156	L1

END OF SEARCH HISTORY

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Search Results -

Terms	Documents
L29 and L5	0

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Search: L32

Refine Search

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Search History

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L31	l5 and L30	0	L31
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L29	(5272638 | 5428545 | 4763270 | 5459667 | 5103400 | 5475387 | 5031104 | 5506779 | 5303159 | 5204817 | 5467276 | 5513110 | 5291412 | 5608635 | 5262775 | 5938720 | 5638280 | 5508930 | 5410485 | 4812990 | 4796189 | 5559511 | 5506774 | 5041983 | 4782447 | 4794528 | 5184303 | 5291414 | 5550538 | 5519619 | 5187667 | 5311434 | 5291413 | 4570227 | 5371678 | 5442349 | 5612881 | 5502640 | 4926336 | 5369588 | 4937753 | 5521826 | 5557522)![PN]	89	L29
L28	('6192314')[PN]	2	L28
L27	(4570227| 4763270| 4782447| 4794528| 4796189| 4812990| 4926336| 4937753| 5031104| 5041983| 5103400| 5184303| 5187667| 5204817| 5262775| 5272638| 5291412| 5291413| 5291414| 5303159| 5311434| 5369588| 5371678| 5410485| 5428545| 5442349| 5459667| 5467276| 5475387| 5502640| 5506774| 5506779| 5508930| 5513110| 5519619| 5521826| 5550538| 5557522| 5559511| 5608635| 5612881| 5638280| 5938720)![pn]	89	L27
L26	('6192314'| '6192314')[URPN]	33	L26

L25	l8 and L24	1	L25
L24	plurality same (route or road)	53823	L24
L23	l20 and L21	1	L23
L22	l8 and L21	2	L22
L21	user or driver	2164510	L21
L20	select$ and l8	1	L20
L19	increas$3 and l8	1	L19
L18	l8 and list	1	L18
L17	transit and l8	0	L17
L16	cell and l8	0	L16
L15	l8 and L14	1	L15
L14	circular or square	2219600	L14
L13	map and l8	2	L13
L12	l10 and L11	1	L12
L11	low$5	8770583	L11
L10	l8 and L9	1	L10
L9	cost	2521308	L9
L8	6192314.pn.	2	L8
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END OF SEARCH HISTORY